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This is a requst for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

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Additional inventors are being named on the _____ separately numbered sheets attached hereto

TITLE OF THE INVENTION (500 characters max)

Sensitive and robust coherent optical detection of transient motion from a scattering surface using detector arrays

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ENCLOSED APPLICATION PARTS *(check all that apply)*

[✔] Specification *Number of Pages* 4   [ ] CD(s), Number _____

[✔] Drawing(s) *Number of Sheets* 4   [ ] Other (specify) _____

[ ] Application Date Sheet. See 37 CFR 1.76

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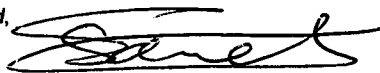[ ] Payment by credit card. Form PTO-2038 is attached.

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[Page 1 of 2]

Respectfully submitted,

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Sensitive and robust coherent optical detection of transient motion from a scattering surface using detector arrays

Abstract

A method and apparatus for optical detection of transient surface motion. A probe laser beam is directed onto the surface of interest. The laser light back reflected or scattered by the surface is received and is made to interfere with a reference beam onto one or more detector arrays. No stabilization of the optical path is required. Detection of the small surface displacement is achieved by processing and combining the multi-detector signals, either (*) using optical setup of Figure 1 and by processing of the two sets of quadrature signals A & B with electronic circuitry shown in Figure 3 and Figure 4, or (**) using the simplified optical setup of Figure 2 and by processing of the multiple speckle (random) signals using the approximate processing shown in Figure 5.

This interferometer presents the advantage of long depth-of-field. The depth-of-field of the optical system corresponds to the depth-of-field of the equivalent small aperture of each single-channel. It is well known that small aperture lead to large depth-of-field. The coherent summation of the independent small aperture signals does not reduce the depth-of-field. The large depth of field corresponding to one of the small aperture of one single channel is preserved for the large aperture, multi-channel optical system.

The apparatus and method in Figure 2 and Figure 5 show a simplified optical configuration and simplified signal processing for reduce cost and size. The system is optimized for detection on scattering surfaces that generate speckle beams. No quadrature detection is required. The system relies on the random nature of the speckle light. If a sufficient number of independent speckle signal are summed, we can assume that the resulting signal corresponds to 50% of in-quadradure signal and 50% of Out-of-quadrature signal.

The apparatus and method used for simplified multi-channel detection give an output signal quasi-proportional to the absolute value of surface displacement. For many ultrasonic applications, the linearity of the detector is not critical. For example, for thickness measurement, measurement of the time of flight is the critical parameter. The measurement accuracy of the signal amplitude is not critical for this application, as long as the signal can be detected with sufficient SNR. A low cost sensing device with inherent non-linearity will lead to equivalent time-of-flight accuracy measurement that a linear system that is more complex and at higher cost.

Claims

1 — A method for increasing the depth-of-field of an interferometer using a large area detector made of a array of detectors instead of a single, small area detector. Interferometer system designed for detection of small transient surface displacements of an optically scattering surface, requires a fast collecting optic for good light collection and thus high sensitivity. The use of fast collecting optic also means that the depth-of-field of the interferometer is small. For sensitive detection of high frequency transient signal, a small area photodiode (with small junction capacitance) is required. The combination of a large collecting aperture with the requirement to focus the collected light onto a small detector area leads to short depth-of-field.

By replacing the small detector with a detector array, the total area of the detector increase, leading to a larger depth-of-field. Each detector signals are amplified and then added to form the final signal. Because each detector has a small junction capacitance, the sensitive detection of transient signal is not compromised.

Interferometers that benefit from this improvement are: Confocal Fabry-Perot, adaptive interferometer based on mixing in a photorefractive material.

Extended depth-of-field is critical for industrial application, where the positioning of the sample often varies.

2 - An apparatus as described in Figure 1 for combining the speckle object beam and the reference beam on detector arrays, including:
  a) An optical system for collecting the speckle beam scattered by the sample
  b) An optical system for expanding the reference beam in order to fill the size of the multi-detector array
  c) A device for inducing, at low frequency, a path variation of the reference beam superior to one wavelength ($>2\pi$ phase change). The system could be a mirror or a prism mounted with speaker, piezo actuator, or shaker.
  d) four detector arrays for detecting the interference signal between the object speckle beam and the reference beam. The arrays are used in pair for balanced detection. The pair A and the pair B give signals in quadrature.

3 — A simplified apparatus as described in Figure 2 for combining the speckle object beam and the reference beam on detector arrays, including:
  e) An optical system for collecting the speckle beam scattered by the sample
  f) An optical system for expanding the reference beam in order to fill the size of the detector array
  g) A device for inducing, at low frequency, a path variation of the reference beam superior to one wavelength ($>2\pi$ phase change). The system could be a mirror or a prism mounted with speaker, piezo actuator, or shaker.
  h) One or two detector arrays for detecting the interference signal between the object speckle beam and the reference beam.

No quadrature or balanced detection is performed in this setup. It uses only a minimum number of optical components (compared to setup shown Figure 1)

4 - A method for demodulation and combination of the signal from the detector arrays, as described in Figure 5, including:
  a) photodiode signal amplification
  b) High-pass filtering
  c) Rectification
  d) Summation of all the rectified signals.

The high frequency ultrasonic signal is filtered out using high-pass filter. The high frequency ultrasonic signal is amplified and rectified. In case of a Quadrature interferometer (Figure 1), both rectified quadrature signals are added. The amplitude of the signal is then proportional to $Abs[Sin(\phi)]+Abs[Cos(\phi)]$, where ϕ is the slow varying (low Frequency) phase difference between the object beam and reference beam. $Abs[Sin(\phi)]+Abs[Cos(\phi)]$ varies between 1 and 1.4 for ϕ varying between 0 to 360 degrees.

For detection of speckle beam using multi-detectors the quadrature optical setup (Figure 1) is not required. The simpler optical setup shown Figure 2 can be used. Here we take advantage of the random distribution of the speckle phase that will ensure that in average the detector signal are equally split between the two quadrature components: $Sin(\phi)$ and $Cos(\phi)$.

An example of a compact Amplification & demodulation is shown in Figure 6. The frequency filtering, transimpedance amplification and rectification is done by a single amplifier. This simplified amplification/demodulation, requiring minimum number of components, is well suited for array with large number of detectors.

5 - A method for introducing absolute calibration by:
  a) Introducing a low frequency phase modulation superior to 2π.
  b) Using an Automatic Gain Control (AGC) circuitry to keep the 2π modulation signal of constant amplitude before demodulation.
  c) To remove the modulation by low frequency filtering after demodulation processing.

A more than 2π (one wavelength) phase modulation at low frequency is introduced between the reference and object beam. This low frequency phase modulation can be introduced for example on the reference beam using a vibrating mirror (Figure 1 and Figure 2). The amplitude of the modulation is not critical, as long as it is superior to 2π. The peak-to-peak amplitude of the detected calibration signal is bounded to be at maximum two times the wavelength. By keeping the peak-to-peak amplitude of the detected calibration signal constant, we now have a direct conversion between signal amplitude and displacement. The transient (high frequency) ultrasonic signal is now absolutely calibrated. The peak-to-peak calibration signal is simply kept at constant amplitude using an AGC. The calibration signal is then separated from the transient ultrasonic signal by low-pass frequency filtering as the two signals are at well separated

frequencies: Low frequency (<10kHz) for the calibration signal and high frequency (>10kHz) for the transient ultrasonic signal.

6 - A method where only one AGC is needed to perform the absolute calibration with the detector arrays by (See figure 7):

   a) Introducing a low frequency phase modulation superior to 2π, as for Claim 5.
   b) High-pass filtering reduce the amplitude of the calibration to small level, comparable to the amplitude of the high frequency transient surface motion
   c) Signal is amplified and rectified
   d) After summation of all the rectified signals, the AGC maintain the calibration signal to constant level
   e) The low frequency calibration signal is then filter-out from the ultrasonic signal

First, the large amplitude, low frequency calibration signal is partially removed by the high pass filter. The amplitude of the low frequency calibration signal after high-pass filtering is of comparable amplitude with small amplitude transient ultrasonic signal of interest. After amplification, rectification and summation of the multi-channels, the low frequency calibration is extracted and used for control of the AGC. A High-pass filter is then used to suppress the low frequency calibration signal from the output signal and to only deliver the high frequency transient ultrasonic signal at the output.
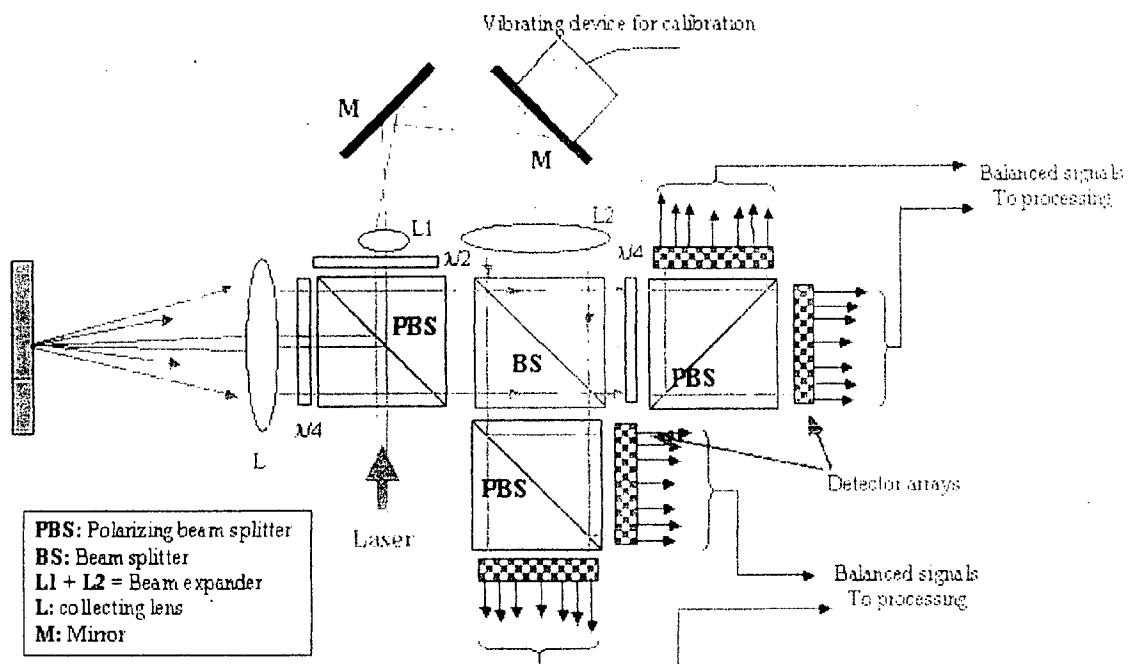
Figure 1: Optical setup of the Interferometer with Balanced and Quadrature detection
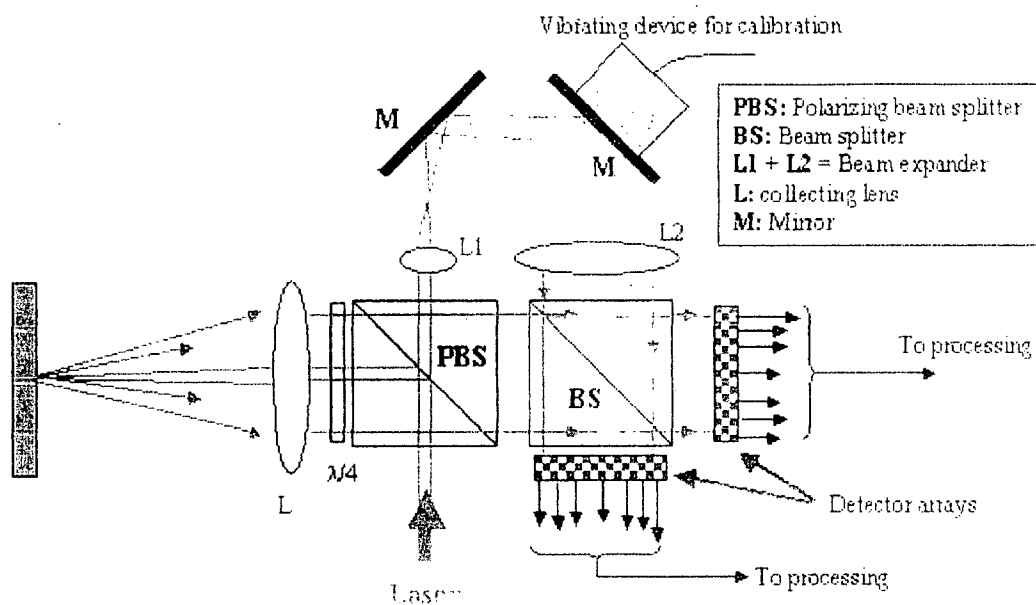

Figure 2: Simplified Optical setup of Interferometer with array of large number of channels
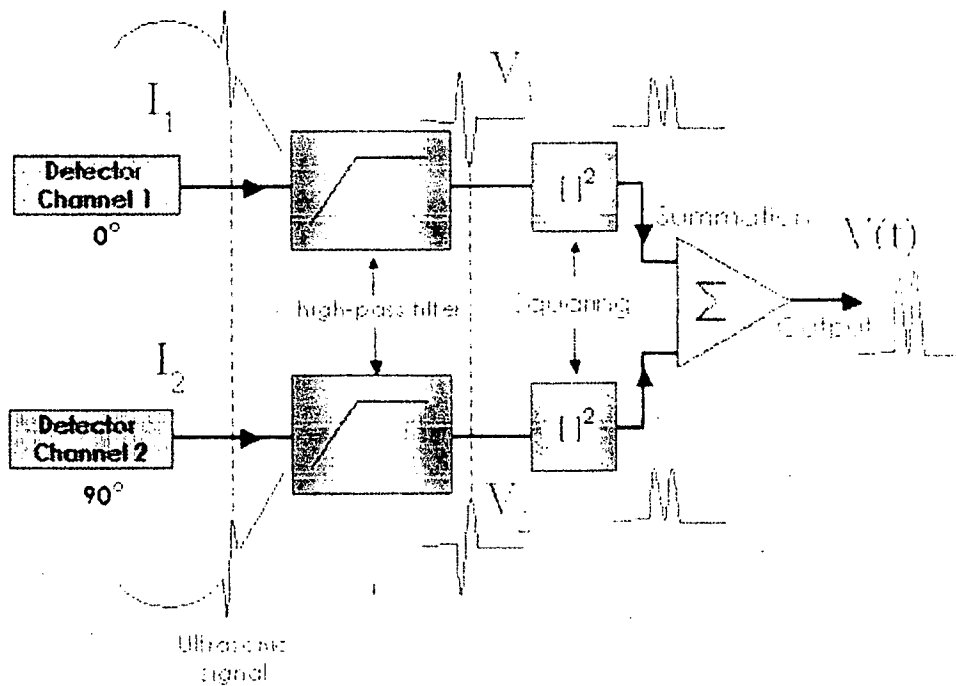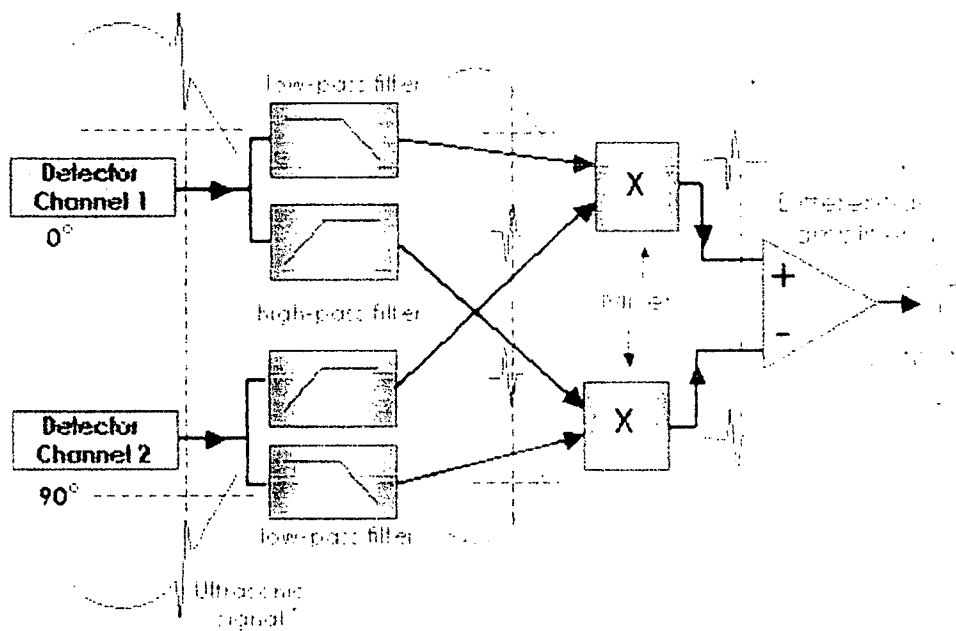
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Figure 3: Electronic processing for quadrature interferometer: Output proportional to square of displacement

Figure 4: Electronic processing for quadrature interferometer: Output proportional to displacement

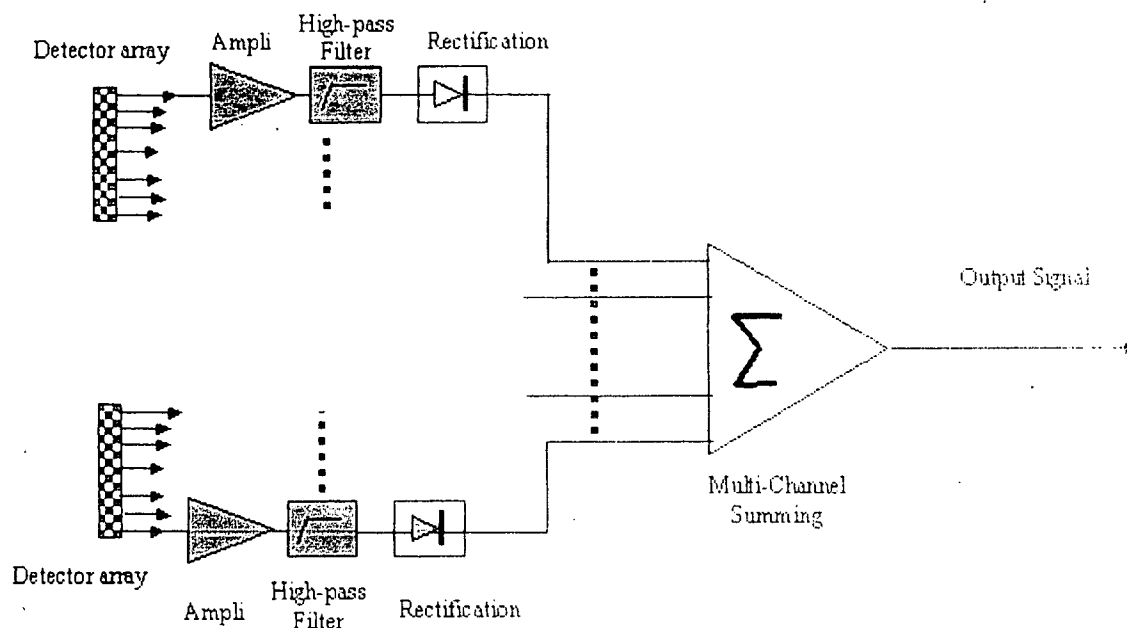*Bossa Nova Technologies*

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Figure 5: Approximate Electronic processing for array with large number of channels: Output approximately proportional to absolute value of displacement.
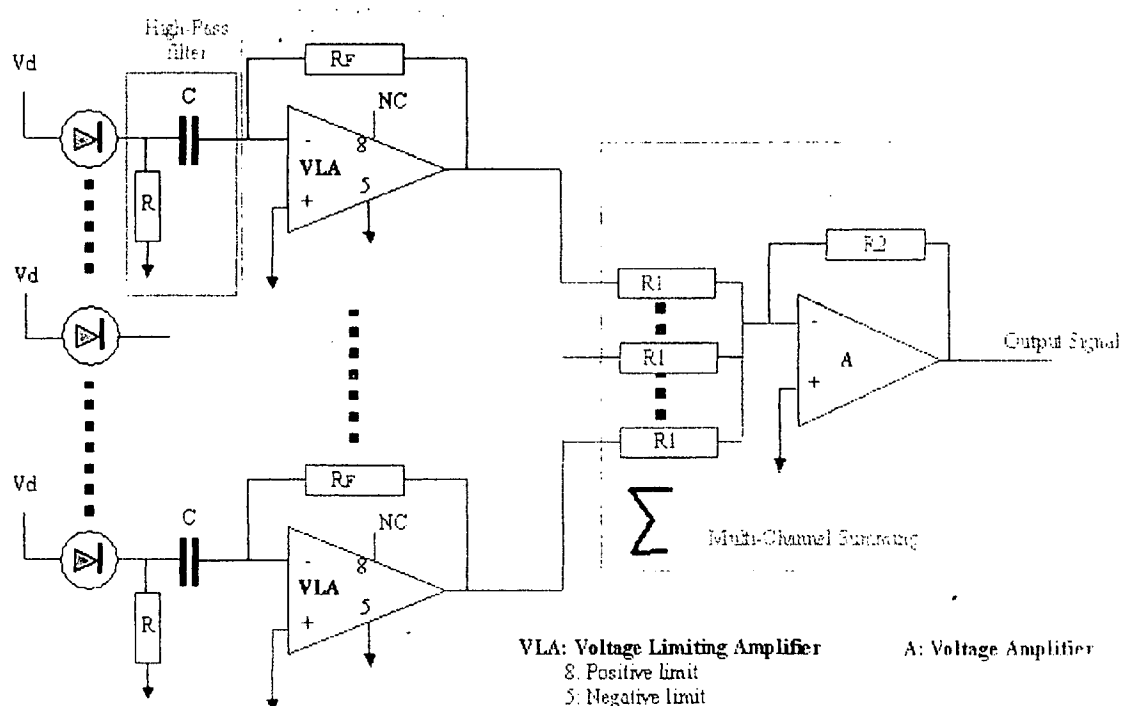

Figure 6: Example of simple circuitry implementation for processing of signal from array with large number of channels
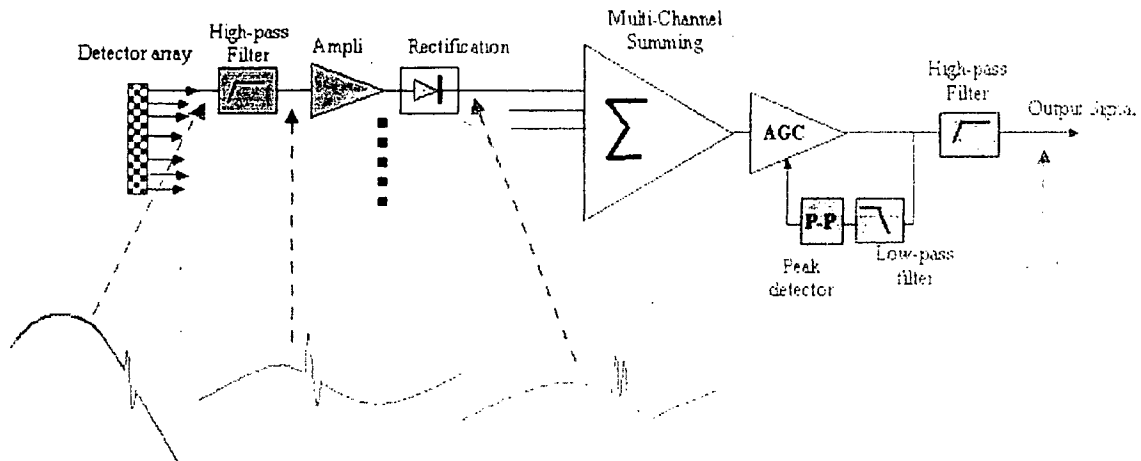
Figure 7: Electronic processing for array with large number of channels, with automatic calibration of output signal: Output approximately proportional to absolute value of displacement.